The Longitudinal Proton Structure Function at HERA

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The longitudinal proton structure function (F_L) has been measured at the HERA collider in positron-proton deep inelastic scattering collisions with the H1 and ZEUS detectors. This measurement is achieved by using multiple center-of-mass energies ($\sqrt{s}$) via a reduction of the proton beam energy. The energies used for this measurement are $\sqrt{s}$ = 318, 251, 225 GeV. The kinematic region studied is $2.5 < Q^2 < 800\ GeV^2$. H1 and ZEUS data have been combined to increase statistical precision and reduce systematic effects. The impact of the low proton beam energy cross sections to the proton PDFs is being investigated.

1. INTRODUCTION

The $e^{\pm}p$ deep inelastic scattering (DIS) cross section can be represented as the sum of the two structure functions F_2 and F_L, as

$$\sigma_r = \frac{d^2\sigma}{dxdQ^2}\frac{Q^4x}{2\pi\alpha^2 Y_+} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \quad (1)$$

where α is the fine structure constant, Q^2 is the virtuality of the exchanged boson, x is the Bjorken scaling variable, y is the electron inelasticity and $Y_+ \equiv 1 + (1-y)^2$.

F_2 is the dominant term in this cross section throughout most of the kinematic range. The magnitude of F_L is proportional to the cross section for probing the proton with a longitudinally polarized virtual photon (σ_L).

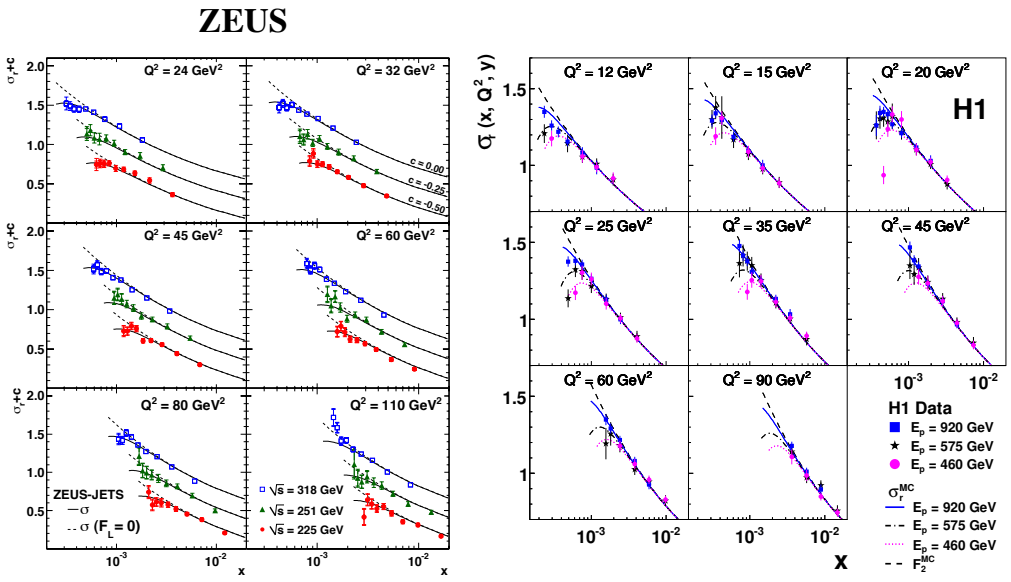
A measurement of F_L is technically challenging and requires a measurement of the DIS cross section at the same x and Q^2 while varying y. From the relation $Q^2 = sxy$, it is clear that this can be achieved only by varying s, the center-of-mass energy. Before HERA ceased operations in July 2007, the proton beam energy was lowered from its nominal energy of 920 GeV to 460 GeV and 575 GeV to facilitate this measurement.

2. THE LONGITUDINAL PROTON STRUCTURE FUNCTION F_L

In the Quark Parton Model (QPM), all of the proton's momentum is carried by the quarks. F_2 is equal to the sum of quark and anti-quark x distributions weighted by the square of the electric charges, furthermore F_L is exactly zero. In Quantum Chromodynamics (QCD), F_L no longer needs to be zero as it receives contributions from both quarks and gluons. In DIS at low x the gluon contribution greatly exceeds that of the quarks, making F_L a direct measure of the gluon distribution. Scaling violations in the evolution of F_2 at low-x, as described by the DGLAP QCD evolution equations, have previously been used to constrain the gluon distribution and F_L[1]. An independent measurement of F_L will stand to further our knowledge of the longitudinal structure function and act as a validity test of perturbative QCD in the low Bjorken x region.

3. MEASUREMENT STRATEGY

The reduced cross section (σ_r) is measured for multiple beam energies, as is shown in figures 1(a) and 1(b). F_L and F_2 are extracted simultaneously using a Rosenbluth plot[2]. The same σ_r is measured at each centre-of-mass energy and plotted against y^2/Y_+. Figure 2 demonstrates six such Rosenbluth plots used in the H1 and ZEUS combined measurement. In a Rosenbluth plot F_L is the slope of the line fitted to the points, $F_L(x,Q^2) = -\partial\sigma_r(x,Q^2,y)/\partial(y^2/Y_+)$. F_2 is simply the $y-$intercept of the said line, $F_2(x,Q^2) = \sigma_r(x,Q^2,y=0)$.



(a)ZEUS (b)H1

Figure 1: Measured reduced cross section for different bins of Q^2.

Both the H1 and ZEUS collaborations have independently measured F_L[3, 4]. Combining the measurements from the two experiments has several advantages, firstly, an increase in statistics improves the precision of the measurement. Secondly, uncorrelated errors reduce because they are different for both H1 and ZEUS. The point-to-point correlated errors also reduce because H1 and ZEUS use different methods for reconstructing the event kinematics. To combine the data, results from H1 and ZEUS are corrected to a common x, Q^2 grid. This is done using a swimming technique involving the HERAPDF 1.0 parameterization [5]. The reduced cross sections are combined and then F_L is extracted.

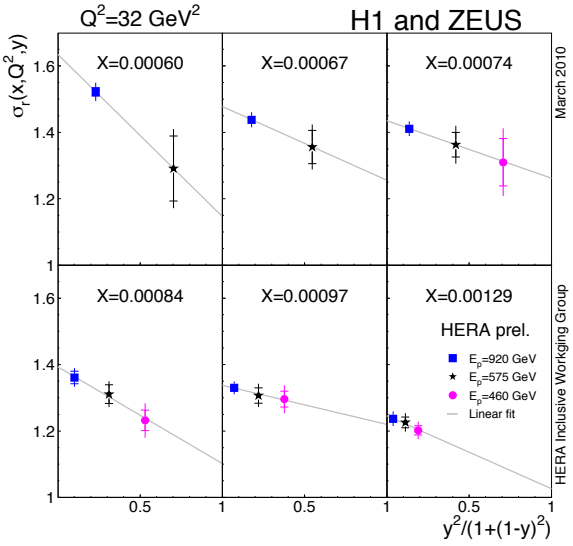


Figure 2: H1 and ZEUS combined measurement of the reduced cross section in a single Q^2 region for different bins of x. F_L is the slope of the line connecting the points.

4. RESULTS

This measurement covers a wide kinematic range, spanning $2.5 < Q^2 < 800\text{GeV}^2$ and $0.0006 < x < 0.0036$. The combined results for F_L are shown in figure 3. In figure 4(a) each Q^2 bin is averaged over all the measured x values to obtain a single x bin. The results are compared with the HERAPDF 1.0 PDF set. Good agreement is demonstrated for $Q^2 > 10\text{GeV}^2$ while at low Q^2 measurements deviate from NLO QCD predictions. In general results are consistent with non-zero F_L. H1 and ZEUS combined results are now being used to improve the HERAPDF 1.0 parameterization sets. Figure 4(b) is an example of one such parameterization and compares the PDF set with and without the inclusion of $\sqrt{s} = 251$ & 225 GeV data. The two PDF sets agree within the total uncertainty of HERAPDF 1.0, supporting the expectations of perturbative QCD.

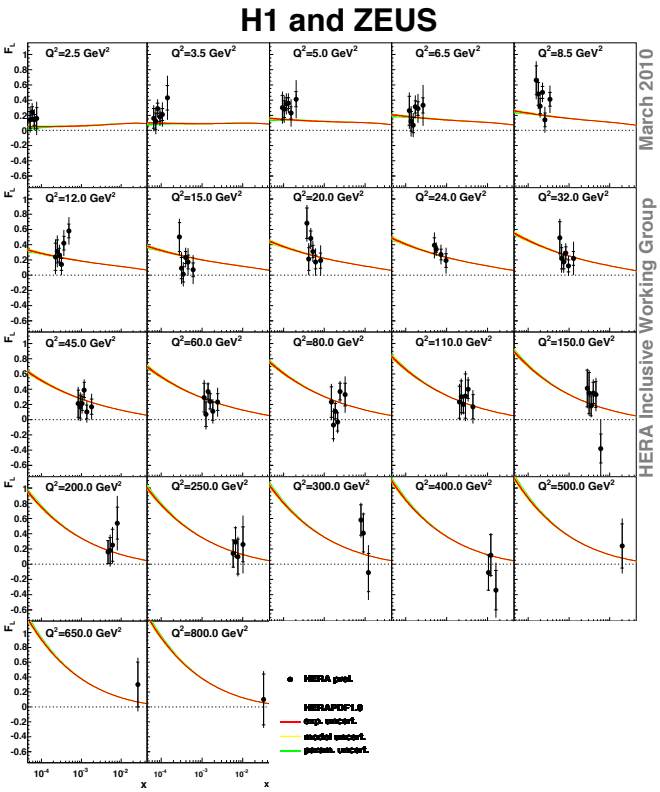
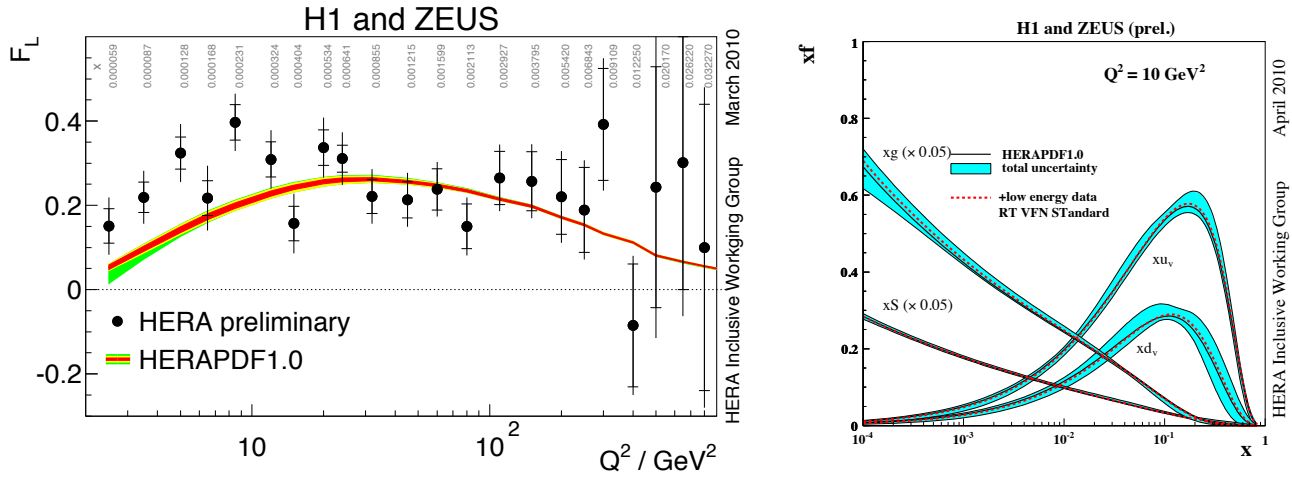


Figure 3: Combined H1 and ZEUS F_L measurement.



(a) (b)

Figure 4: 4(a) Combined H1 and ZEUS F_L measurement as a function of Q^2 averaged over x. 4(b) Proton Parton Distribution Functions (PDF) for u, d, Sea and Gluons. Dashed line represents PDFs with low energy cross sections included.

References

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